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REVIEW AND EVALUATION OF GROUND STRESSES AT CAMPBELL RED LAKE MINE, ONTARIO

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REVIEW AND EVALUATION OF GROUND STRESSES AT CAMPBELL RED LAKE MINE, ONTARIO

by

B. Arjang*

ABSTRACT

A cooperative program between CANMET and Campbell Red Lake Mine was conducted to determine the field stress around the multiple ore zones. Field stresses were determined from the strain recovery measurements of twenty-one overcoring tests carried out at various depths from 580 m to 1220 m.

The results indicated an increase of vertical and horizontal stresses with depth, with an average horizontal stress/vertical stress ratio of 1.7 $\pm$ 0.44. The major principal stress prevailed a horizontal NE/SW trend, acting nearly perpendicular to the steeply dipping ore zones. The measured vertical stress component approached the overburden weight.

A comparison suggested that the field stress values fit in the range of data observed in the Canadian Shield, and no extreme stress gradients were obtained at the stress determination sites.

The most suitable pre-mining stresses for the application of computer modelling were:

Vertical stress : 0.0265 MN/m^3 x depth (m) in MPa

Pre-mining stress perpendicular to orebody : 2.1 x vertical stress

Pre-mining stress parallel to orebody : 1.2 x vertical stress

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Key words: Field stress; Stress gradients; Triaxial strain cell.

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ÉTUDE ET ÉVALUATION DES CONTRAINTES DU TERRAIN À LA MINE CAMPBELL RED LAKE (ONTARIO)

par

B. Arjang*

RÉSUMÉ

CANMET et Campbell Red Lake Mine ont collaboré à la réalisation d'un programme qui avait pour but de mesurer les contraintes du terrain autour des nombreuses zones minéralisées. Les contraintes de terrain ont été calculées à partir des résultats obtenus des mesures de récupération de la déformation de 21 essais de surcarrottage effectués à diverses profondeurs allant de 580 m à 1220 m.

Les résultats obtenus ont indiqué une augmentation en profondeur des contraintes verticales et horizontales et un rapport moyen de contraintes horizontales/contraintes verticales de 1,7 ± 0,44. La contrainte principale domine dans le sens horizontal N-E/S-O, suivant presque perpendiculairement les zones minéralisées à pendage raide. La composante de la contrainte verticale mesurée approchait le poids du mort-terrain.

Une comparaison des résultats a indiqué que les valeurs des contraintes de champs se rangent dans la gamme des données observées dans le Bouclier canadien, et qu'aucun gradient extrême de contrainte n'a été obtenu dans les sites où les contraintes ont été mesurées.

Les contraintes pré-exploitation les plus propices à l'application de la modélisation sur ordinateur étaient :

Contrainte verticale : 0,0265MN/m^3 x profondeur (m) en MPa

Contrainte pré-exploitation perpendiculaire au gisement :

2,1 x contrainte verticale

Contrainte pré-exploitation parallèle au gisement :

1,2 x contrainte verticale.

Mots-clés : Contrainte de champs; gradients de contrainte; cellule de déformation triaxiale.

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INTRODUCTION

The Campbell Red Lake Mine, situated in the Red Lake District of Northwestern Ontario, has experienced ground problems and rockbursts since the early 1960's. The most significant rockbursts occurred during recovery of the crown pillars of shrinkage or cut-and-fill stopes. The ground problems have been mainly confined to the narrow NW-SE striking ore zones.

To determine the pre-mining and mining-induced ground stresses around the multiple ore zones, CANMET, in cooperation with Campbell Red Lake Mine (CRL Mine) conducted a series of stress measurements. Results from the first phase of this project, "Field and pillar stress determinations", have been presented earlier (1). The present report incorporates data obtained from the second phase of measurements and provides a review and evaluation of field stress determinations carried out at CRL Mine.

Figure 1 shows the general geology of the Red Lake area and the location of the mine. Detailed information on the regional and local geological setting is given in the literature references (2,3).

The in situ stress measurements were performed at different mine levels in the vicinity of various ore zones designated as A, F, G, L and S zones. With overcoring testing procedures, using CSIR triaxial strain cells, a total of 21 strain recovery measurements were attempted.

FIELD STRESS MEASUREMENTS

For the strain recovery measurements, five sites were selected on the 13, 14, 15, 22 and 27 levels at depths from 580 m to 1220 m below surface. The information on test holes, number of measurements and rock type is given in Figures 2 and 3. The measurements were generally taken in areas away from the mining influence. Tests were commenced at distances greater than 3.0 m

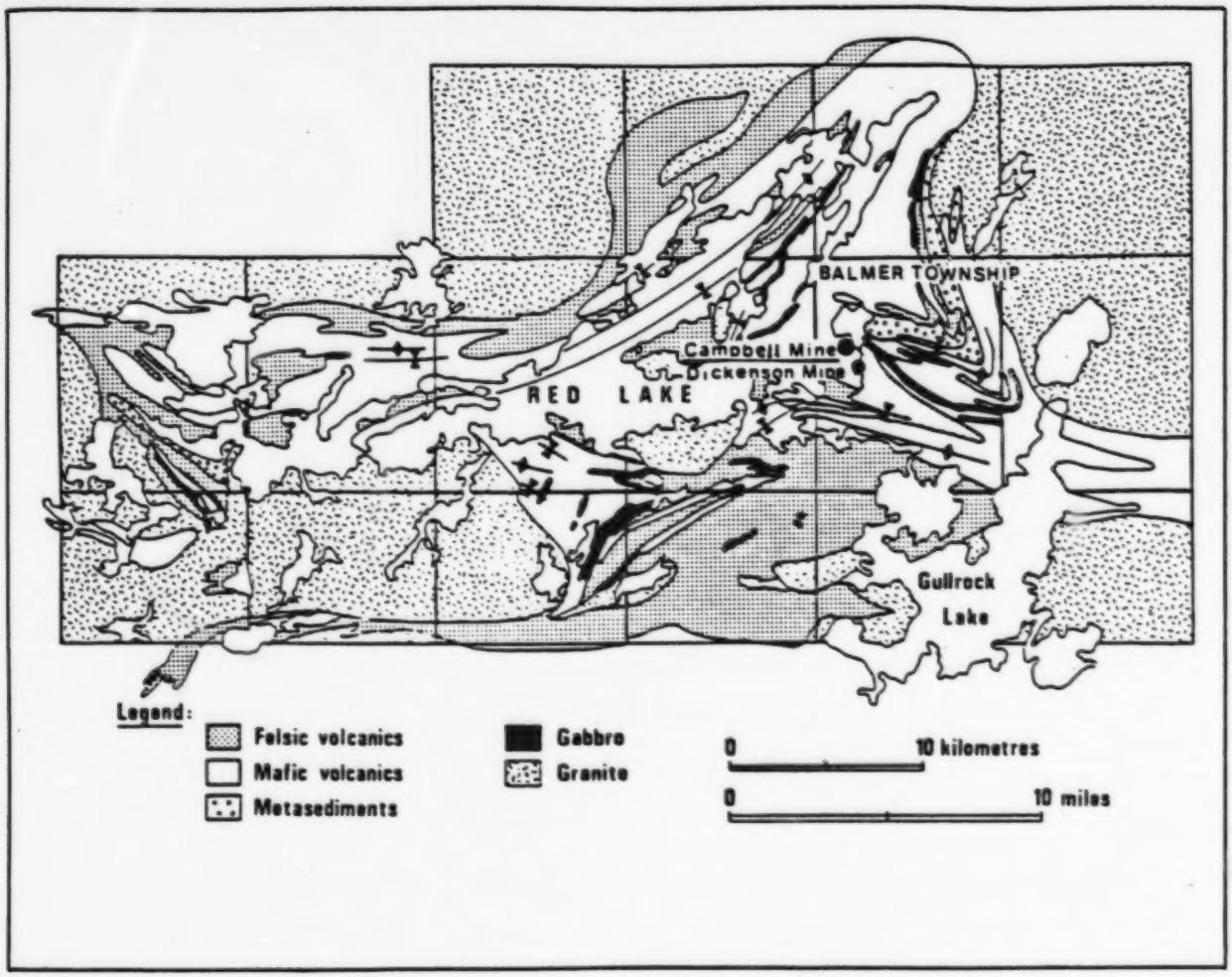
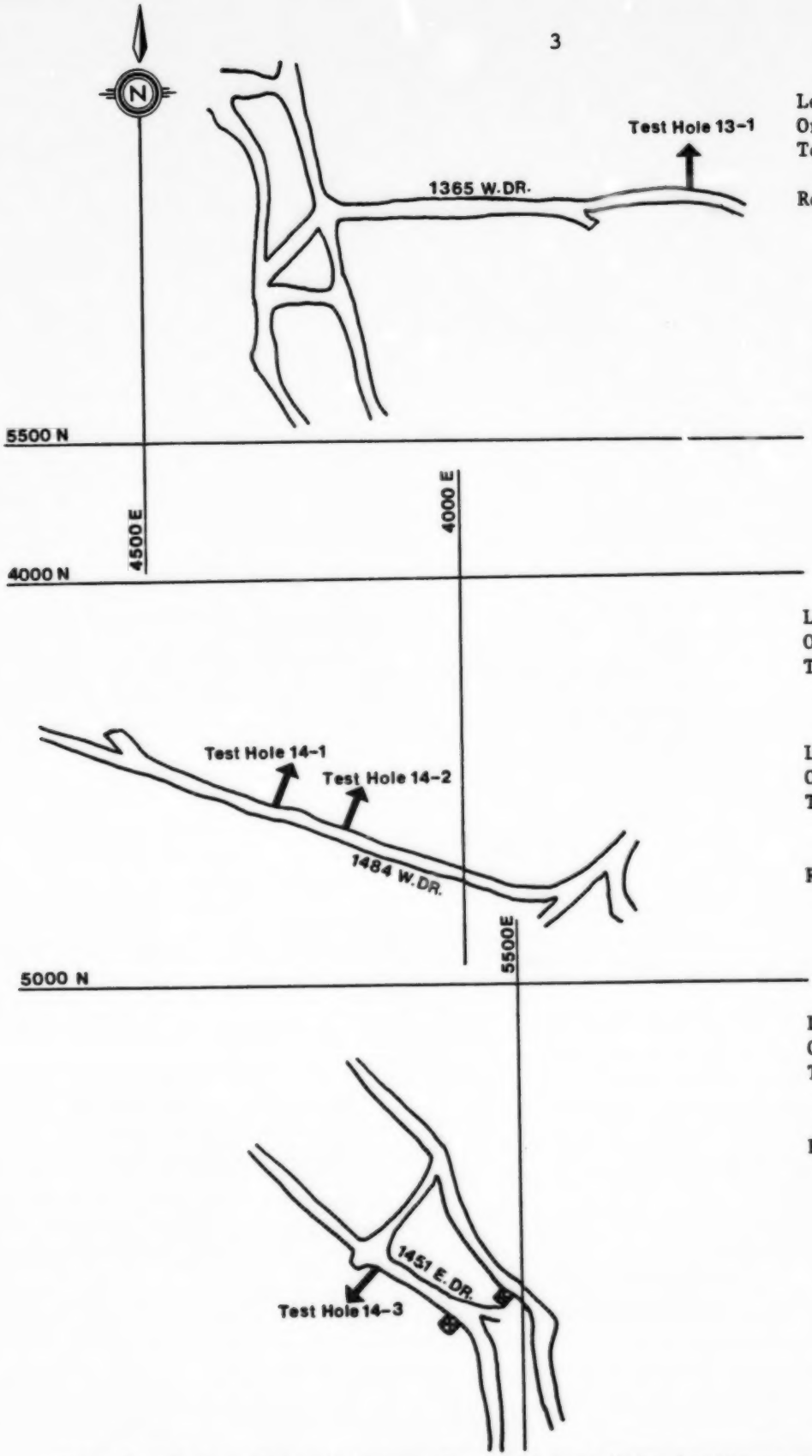


Fig. 1 - Simplified geology of the Red Lake greenstone belt, modified from the O.G.S. Geological Compilation map (2).



13 Level

Location: N5670, E4864
Orientation: 00°/+5°
Test No. CRL 13-1
CRL 13-2
Rock type: Altered rock (Andesite)

14 Level

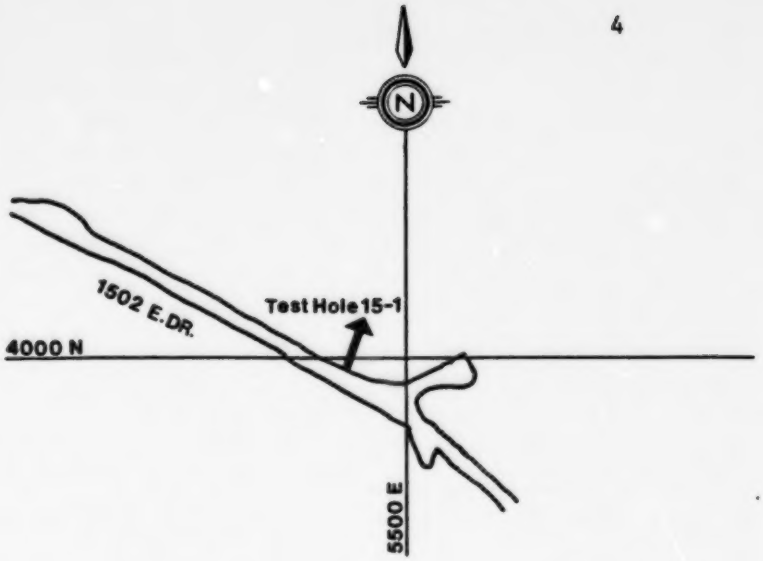
Location: N3848, E3874
Orientation: 25°/+10°
Test No. CRL 14-11
CRL 14-12
CRL 14-13

Location: N3822, E3921
Orientation: 22°/+4°
Test No. CRL 14-21
CRL 14-22
CRL 14-23
Rock type: Andesite

14 Level

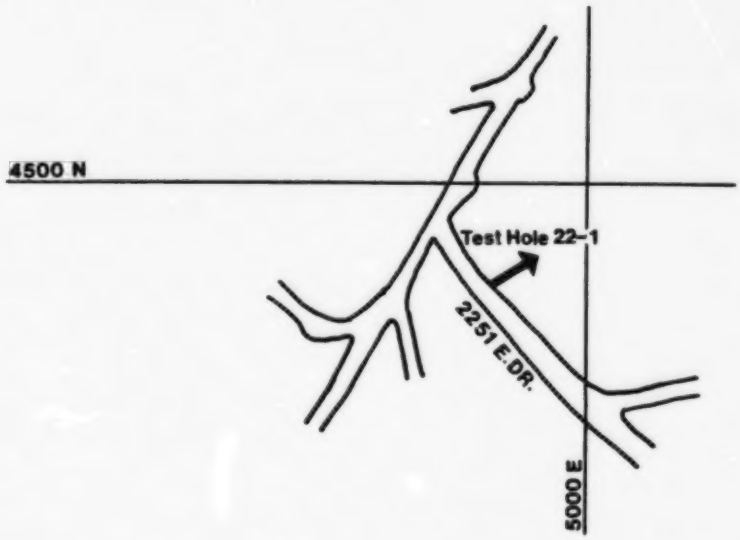
Location: N4808, E5403
Orientation: 244°/+7°
Test No. CRL 14-31
CRL 14-32
CRL 14-33
Rock type: Andesite

Fig. 2 - Stress determination sites and test hole locations on the 13 and 14 levels CRL Mine (not to scale).



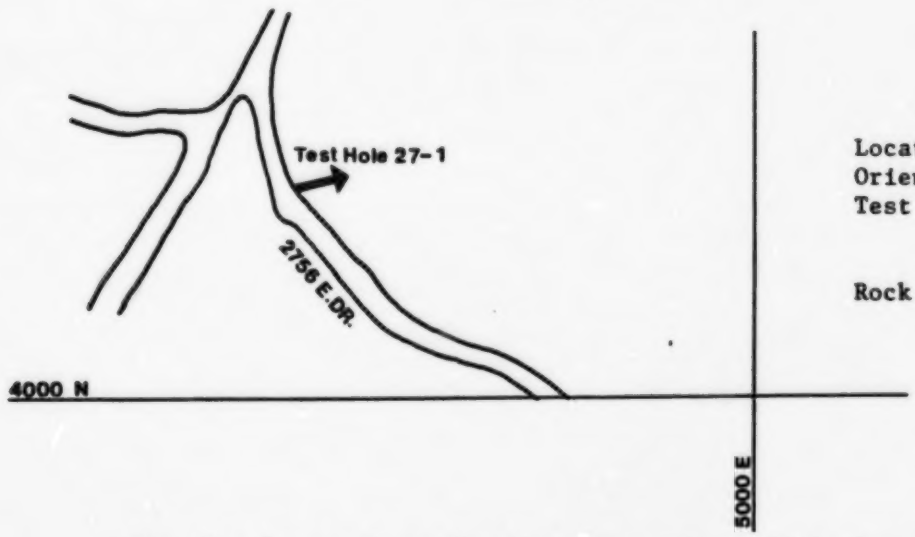
15 Level

Location: N3989, E5465
Orientation: 19°/+5°
Test No. CRL 15-1
CRL 15-2
CRL 15-3
CRL 15-4
Rock type: Andesite



22 Level

Location: N4442, E4942
Orientation: 58°/+13°
Test No. CRL 22-1
CRL 22-2
CRL 22-3
Rock type: Andesite



27 Level

Location: N4114, E4718
Orientation: 75°/+13°
Test No. CRL 27-1
CRL 27-2
CRL 27-3
Rock type: Andesite

Fig. 3 - Stress determination sites and test hole locations on the 15, 22 and 27 levels, CRL Mine (not to scale).

from the wall of the development drifts, which were about 2.6 m square. Three overcoring tests were conducted at each measurement site to increase the reliability of results. Test holes were drilled perpendicular to the main structural trend.

The elastic constants for the rocks intersected at the test holes were determined from available core specimens. Following the standard testing procedure (4), 25 intact core specimens were subjected to uniaxial compression tests. The results of rock property tests are given in Table 1. In most cases, relatively high standard deviations were observed which were indicative of a non-homogeneous composition of the rock type at the stress measurement sites. Therefore, the mean values of the elastic moduli and Poisson's ratios obtained from the individual test sites were used for stress tensor calculations.

To ensure whether valid strain recovery measurements were obtained, a mechanical quality testing of overcored specimens and a preliminary statistical treatment of data were carried out. The bond quality between the strain cell and rock, and the gauge response for linearity were checked during uniaxial compression tests. Gauge responses indicating hysteresis were identified and omitted from stress analysis. A typical plot of gauge responses from 12 gauges of the strain cell is shown in Figure A-1 (Appendix A).

Statistical assessment of strain recovery data followed the procedure given in the literature (5-7). For the individual test hole, the estimated standard deviations of strain readings of similar gauge directions in triaxial cells were compared with the mean standard deviation of all observations. In addition, a cumulative distribution of the difference in strain readings from group means for identical strain gauge directions was obtained as shown in Figures A-2 to A-8 (Appendix A). An example of calculation procedure is

Table 1 - Determination of elastic modulus and Poisson's ratio in uniaxial compression tests (standard deviations in brackets).

Location	Test Hole	No. of Tests	Elastic Modulus GPa	Poisson's Ratio	Method
13 Level: 1365 W.D.R.	CRL 13-1	2	74.3 (7.92)	0.25 (0.00)	*
14 Level: 1484 W.D.R.	CRL 14-1	5	91.7 (3.55)	0.21 (0.01)	**
1484 W.D.R.	CRL 14-2	3	90.5 (3.46)	0.23 (0.02)	*
1451 E.D.R.	CRL 14-3	2	86.5 (21.07)	0.21 (0.00)	*
15 Level: 1502 E.D.R.	CRL 15-1	4	83.5 (9.79)	0.20 (0.01)	*
22 Level: 2251 E.D.R.	CRL 22-1	5	85.3 (7.07)	0.22 (0.01)	**
27 Level: 2756 E.D.R.	CRL 27-1	4	84.8 (9.05)	0.20 (0.01)	**

* Obtained from strain reading of axial and circumferential gauges of strain cell in uniaxial loading of the overcored hollow core cylinder.

** Obtained from unloading cycle in intervals of 12 to 25 MPa, maximum load 37 MPa (solid core cylinder).

Note: specimen diameter: 136 mm; height/diameter ratio: 2.47 $\pm$ 0.02.

demonstrated in Table A-1 (Appendix A). The computer plots for individual test sites show that the observation points lie reasonably close to the linear regression line, indicating data of low standard deviations.

Based on data evaluations, the measurements with extreme deviations and outlier values were rejected and the acceptable strain recoveries were compiled for the final stress calculations. Deletion of some unreliable measurements was necessary to optimize stress output values.

Table 2 provides the elastic strain recoveries from triaxial strain cell measurements. The results of stress tensor calculations in relation to the Mine coordinate system are given in Table 3. The stress analysis resulted in an average standard deviation of 0.54 MPa with average standard errors for the tensor components of about 20%. The principal compressive stress magnitudes and orientations are given in Table 4. Figure 4 illustrates the orientation of principal compressive stresses for the individual stress determination sites.

DISCUSSION OF RESULTS

Generally, the magnitudes of mean stress obtained from the individual tests were comparable with standard deviations ranging from 1.6 to 6.6 MPa. However, differences of up to 20.0 MPa for the magnitudes of the principal stresses were observed at some measurement sites. At 15 level site, consistently high stresses were measured in all tests. A mean stress of about 40% higher was obtained compared with the 14 level site, located only 45 m above the 15 level. This is considered as localized stress concentration and indicates the probable influence of structural parameters in the proximity of the stress determination site.

With the exception of some low magnitudes, the measured vertical stress components approached the range of the overburden weight (0.026 - 0.0324 MN/m^3

Table 2 - Strain recovery from triaxial strain cell measurements, CRL Mine.

Location	Test No.	Test Depth (m)	Elastic Strain Recovery ($\times 10^{-6}$) Gauge No: 1	2	3	4	5	6	7	8	9	10	11	12	SI(*) Rosette No. 1	2	3
13 Level	CRL 13-1	3.65	75	230	-25	-275	635	170	50	550	615	290	65	385	95	35	5
1365 W.DR.	CRL 13-2	4.20	-30	235	70	-220	800	245	65	640	650	360	100	390	25	20	0
14 Level	CRL 14-11	3.90	120	235	190	185	120	340	345	130	140	100	60	110	110	5	10
1484 W.DR.	CRL 14-12	4.30	295	270	130	145	495	235	105	370	80	100	90	80	10	5	10
	CRL 14-13	5.00	135	185	120	80	350	100	145	420	390	280	160	200	10	25	70
	CRL 14-21	3.70	335	315	530	525	140	125	370	345	235	460	130	-20	25	40	75
	CRL 14-22	4.75	80	270	200	5	600	460	-65	50	250	260	210	195	5	25	5
	CRL 14-23	5.85	105	40	60	110	280	105	165	350	70	90	-10	-10	15	10	20
14 Level	CRL 14-31	3.20	190	40	80	230	85	-55	135	280	135	340	165	-90	0	5	50
1451 E.DR.	CRL 14-32	3.65	300	135	190	325	45	30	165	180	-120	75	200	20	30	0	15
	CRL 14-33	4.20	410	180	335	700	205	-35	150	370	75	65	50	-5	135	20	65
15 Level	CRL 15-1	3.35	385	645	165	-140	615	490	180	320	1640	575	150	1265	45	15	50
1502 E.DR.	CRL 15-2	4.30	195	220	60	-5	760	95	-60	640	1500	740	-195	300	40	35	265
	CRL 15-3	4.85	420	480	240	230	2025	770	50	1380	590	575	75	70	50	75	20
	CRL 15-4	5.90	160	-65	50	250	1100	535	155	735	570	640	170	110	25	15	10
22 Level	CRL 22-1	3.50	420	820	360	-80	240	30	395	610	650	340	340	640	40	5	10
2251 E.DR	CRL 22-2	4.40	365	525	250	100	580	60	270	770	340	415	295	230	10	20	10
	CRL 22-3	6.00	675	1240	380	-195	570	-300	375	1230	415	450	400	280	10	16	85
27 Level	CRL 27-1	3.25	445	670	275	15	150	250	900	695	950	905	1300	1160	35	105	185
2756 E.DR.	CRL 27-2	4.15	820	35	-225	525	500	1175	1425	725	790	1765^{+}	1384^{+}	1960^{+}	35	25	-
	CRL 27-3	4.90	915	-30	-225	655	640	1450	1425	750	850	1890^{+}	1715^{+}	2020^{+}	65	135	-

($^{+}$) Strain readings omitted from stress tensor calculation.

* Strain invariance (sum of strains in two orthogonal directions, $\varepsilon_1 + \varepsilon_3 = \varepsilon_2 + \varepsilon_4$).

Table 3 - Stress components from elastic strain recovery measurements, CRL Mine.

Location	Test No.	Stress Components (MPa) Horizontal σ_E	σ_N	Vert. σ_V	Shear Stresses τ_{EN}	τ_{NV}	τ_{VE}	E (GPa)	ν
13 Level	CRL 13-1	25.6	11.9	8.2	2.5	-7.1	-0.1	74.3	0.25
1365 W.DR	CRL 13-2	29.7	16.6	8.3	3.3	-6.0	-1.4	74.3	0.25
14 Level	CRL 14-11	9.2	21.4	9.7	3.9	3.3	-0.04	91.7	0.21
1484 W.DR	CRL 14-12	17.3	14.6	14.5	2.6	0.5	-5.7	91.7	0.21
	CRL 14-13	22.5	16.5	10.8	3.1	-1.6	0.3	91.7	0.21
	CRL 14-21	20.3	28.6	19.4	14.3	4.6	3.2	90.5	0.23
	CRL 14-22	18.1	20.6	11.3	-3.6	1.5	-3.5	90.5	0.23
	CRL 14-23*	12.3	7.5	6.8	3.1	1.5	-3.1	90.5	0.23
14 Level	CRL 14-31*	17.2	1.9	8.9	3.6	-1.4	-3.5	86.5	0.21
1451 E.DR	CRL 14-32*	10.8	6.8	10.6	8.8	-2.8	-0.6	86.5	0.21
	CRL 14-33	17.9	8.2	19.5	7.0	-4.4	-1.8	86.5	0.21
15 Level	CRL 15-1	42.9	39.9	26.5	-13.5	-15.1	7.6	83.5	0.20
1502 E.DR	CRL 15-2	47.6	5.5	20.9	-4.8	-7.0	6.4	83.5	0.20
	CRL 15-3*	62.4	24.8	33.0	1.0	4.5	-17.6	83.5	0.20
	CRL 15-4	41.1	17.5	18.1	0.8	7.5	-3.7	83.5	0.20
22 Level	CRL 22-1	41.8	28.6	16.5	9.7	-10.0	-5.5	85.3	0.22
2251 E.DR	CRL 22-2	40.7	18.4	17.5	1.4	-1.7	-4.2	85.3	0.22
	CRL 22-3	61.8	18.7	20.9	5.7	-11.6	-15.4	85.3	0.22
27 Level	CRL 27-1*	78.0	37.2	21.2	12.6	-10.9	4.5	84.8	0.20
2756 E.DR	CRL 27-2	55.9	43.1	37.9	8.5	4.5	14.2	84.8	0.20
	CRL 27-3	56.7	49.7	43.7	9.9	7.5	16.3	84.8	0.20

(*) Tests not included in final evaluation as given in Table 5.

Table 4 - Magnitude and orientation of the principal stresses from elastic strain recovery measurements, CRL Mine.

Location	Test No.	σ_1 (MPa)	Brg/Dip*	σ_2 (MPa)	Brg/Dip	σ_3 (MPa)	Brg/Dip
13 Level	CRL 13-1	26.2	078/05	16.9	344/38	2.6	174/52
1365 W.DR	CRL 13-2	30.8	074/08	18.6	340/26	5.1	179/62
14 Level	CRL 14-11	23.2	195/13	9.5	086/55	7.5	293/31
1484 W.DR	CRL 14-12	22.2	074/35	15.0	183/25	9.2	300/45
	CRL 14-13	23.8	067/02	15.7	336/18	10.2	162/72
	CRL 14-21	40.8	217/15	17.9	042/75	9.5	307/01
	CRL 14-22	24.0	141/15	16.1	046/17	9.8	270/67
	CRL 14-23**	14.5	069/17	8.6	176/43	3.5	323/43
14 Level	CRL 14-31**	19.3	077/20	7.7	272/70	1.0	168/05
1451 E.DR	CRL 14-32**	18.5	050/16	10.2	262/71	-0.5	143/09
	CRL 14-33	24.5	056/38	17.2	258/49	3.9	155/11
15 Level	CRL 15-1	62.2	317/24	30.6	058/23	16.6	185/55
1502 E.DR	CRL 15-2	49.9	278/14	21.3	042/65	2.6	183/20
	CRL 15-3**	70.7	089/25	27.2	202/40	22.3	336/40
	CRL 15-4	41.7	091/09	25.0	190/44	10.0	352/44
22 Level	CRL 22-1	49.8	058/17	26.2	321/23	10.9	180/61
2251 E.DR	CRL 22-2	41.6	086/10	19.0	351/26	15.3	195/62
	CRL 22-3	68.6	079/20	25.5	333/37	7.2	195/47
27 Level	CRL 27-1**	81.6	254/01	40.7	345/31	14.1	162/59
2756 E.DR	CRL 27-2	67.4	246/27	39.3	341/11	30.1	092/61
	CRL 27-3	74.1	238/30	43.5	336/12	32.6	085/57

(*) Bearing and dip in degrees in the Mine coordinate system (Grid North = True North).

(**) Tests not included in the final evaluation given in Table 5.

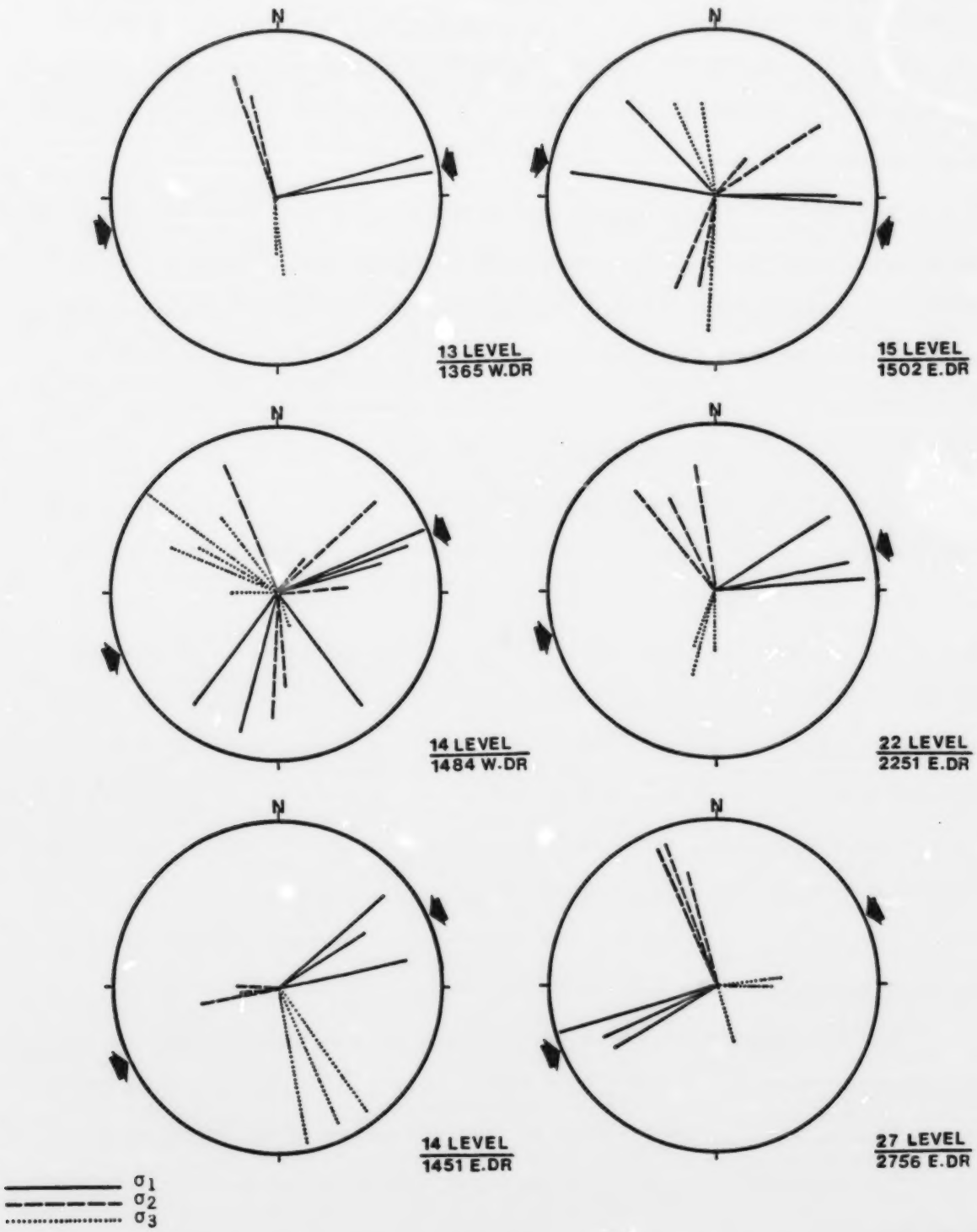


Fig. 4 - Orientation of the principal compressive stresses from Mine Grid North in an equal area net, lower hemisphere projection, (Grid North = True North). ◗ σ_1 mean direction.

x Depth (m) in MPa). The effects of test location, local geological setting and changes in the density of the overburden rocks could provide a possible explanation for the deviation of the vertical component of the in situ stress from overburden stress.

Generally, for each stress determination site, good correlation exists between the directions of major principal stresses. The orientation of major principal compressive stresses on the 13, 14, 22 and 27 levels shows a horizontal NE/SW trend with mean bearing and dip of $75^{o}/15^{o}$. On the 15 level, the direction of major principal compressive stress shows a rotation by about 30^{o} to line up with the main trend.

Comparing the individual stress determination sites, the orientation of the intermediate and minor principal compressive stresses present a large scatter. Dip directions for major, intermediate and minor principal compressive stresses average 15^{o}, 30^{o} and 52^{o}, respectively, indicating that the major principal stress acts in a horizontal, the intermediate principal stress in a sub-horizontal, and the minor principal stress in a nearly vertical plane.

Figure 5 illustrates the mean direction of the major principal compressive stress, and the general trend of ore zones, plotted on the 14 level Mine plan. With regard to the main trend of steeply dipping ore zones, the major principal compressive stress direction is almost perpendicular.

Based on representative values, the average horizontal stress/vertical stress ratio ranged from 1.0 to 2.6 with a mean value of 1.72 ± 0.44. A low stress ratio, e.g., at CRL 14-3 site, is indicative of disturbance in the stress field, probably caused by extensive mining in the proximity of the test location.

A non-hydrostatic stress condition is apparent, since the horizontal stress values differ from each other, and from the vertical stress. Shear

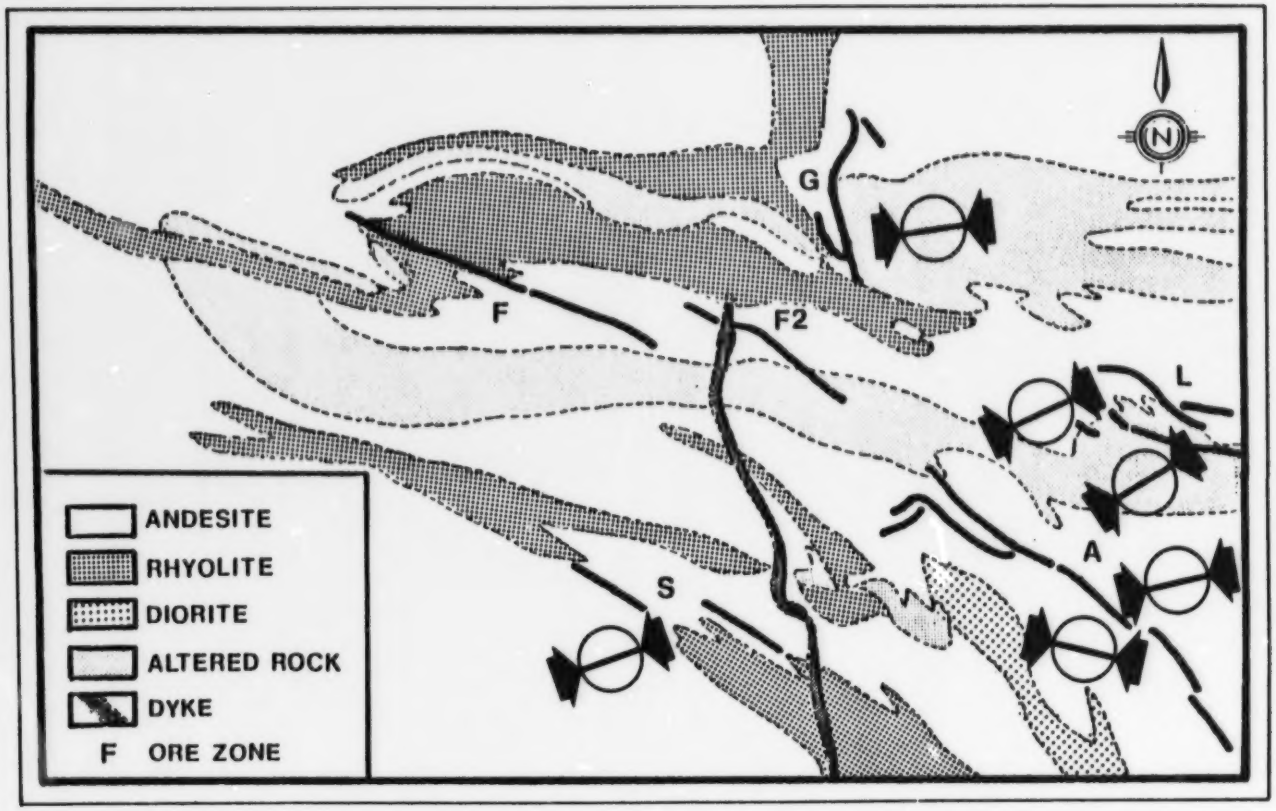


Fig. 5 - Major principal compressive stress directions from stress determinations on the 13, 14, 15, 22 and 27 levels, CRL Mine (14 level plan).

stresses of low magnitudes or tensional were determined.

Figure 6 shows the increase of vertical and average horizontal stress as well as the variation of average horizontal/vertical stress with depth from the stress determinations in the Canadian Shield (8). Field stress data determined at the CRL Mine are also plotted on this Figure. A comparison suggests that the field stress data generally follow the trend established in the Canadian Shield. Data plots, however, indicate that the values from CRL Mine are confined to the average and lower range of the referenced data and no extreme stress gradients were obtained at the stress determination sites.

From the ground stress determinations, the pre-mining vertical stress and horizontal stresses perpendicular and parallel to the ore zones were evaluated as given in Table 5. The stress data provide the representative and combined values from the individual test sites.

The average stress gradients from measurements at depth between 580 to 1220 were obtained from the pre-mining stress components, as shown in data plots in Figure 6. From these gradients the most suitable input stresses for computer modelling can best be approximated as follows:

Vertical stress, σ_V = 0.0265 MN/m^3 x Depth (m) in MPa

Pre-mining stress perpendicular to orebody = 2.1 x σ_V

Pre-mining stress parallel to orebody = 1.2 x σ_V.

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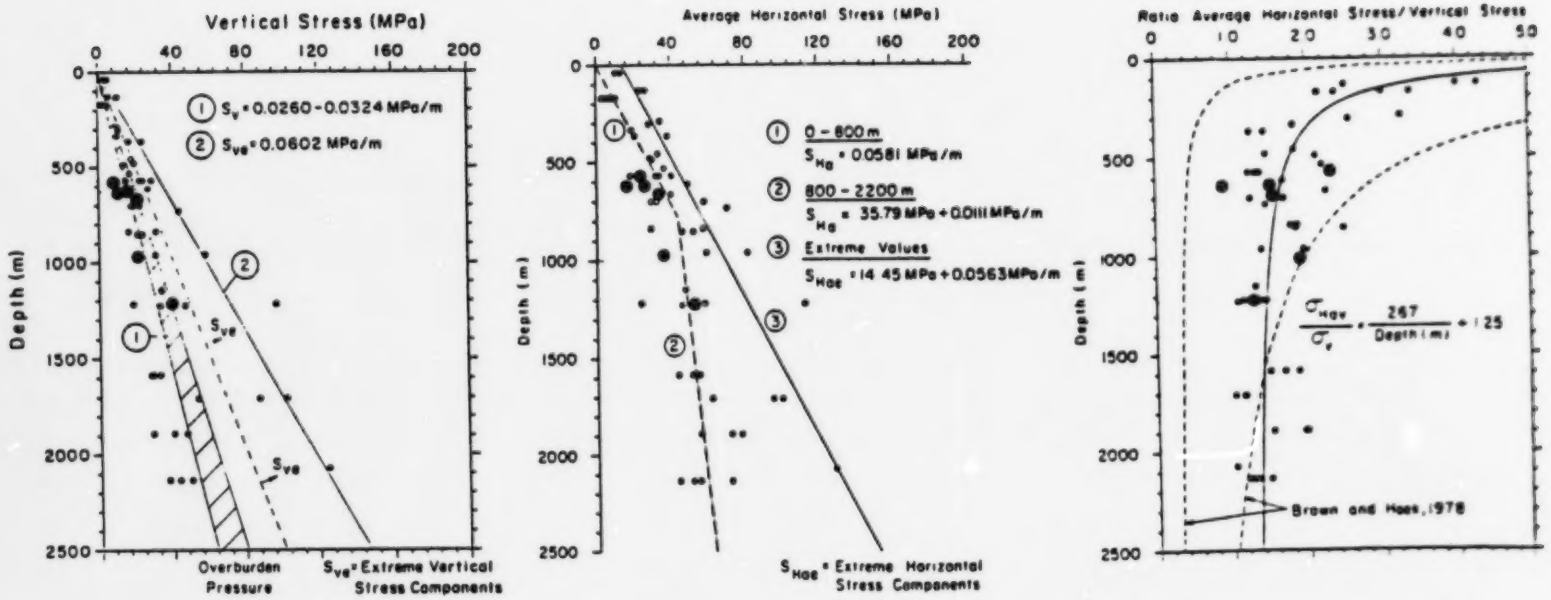
Vertical Stress (MPa)
0 40 80 120 160 200
Depth (m)
0 500 1000 1500 2000 2500
① S_v = 0.0260 - 0.0324 MPa/m
② S_{ve} = 0.0602 MPa/m
S_{ve}
S_{ve}
Overburden Pressure
S_{ve} = Extreme Vertical Stress Components
Average Horizontal Stress (MPa)
0 40 80 120 160 200
Depth (m)
0 500 1000 1500 2000 2500
① 0 - 800 m
S_{Ha} = 0.0581 MPa/m
② 800 - 2200 m
S_{Ha} = 35.79 MPa + 0.0111 MPa/m
③ Extreme Values
S_{Hae} = 14.45 MPa + 0.0563 MPa/m
S_{Hae} = Extreme Horizontal Stress Components
Ratio Average Horizontal Stress / Vertical Stress
0 10 20 30 40 50
Depth (m)
0 500 1000 1500 2000 2500
$\frac{\sigma_{Hav}}{\sigma_v} = \frac{267}{\text{Depth (m)}} + 1.25$
Brown and Hoek, 1978

Fig. 6 - Increase of vertical (σv), average horizontal stress (σHa) with depth, and variation of stress ratio (σHa/σv) as a function of depth in the Canadian Shield (8). (●) values from stress determinations at CRL Mine.

Table 5 - Evaluation of pre-mining stresses, CRL Mine. (Stress in MPa).

Location	Depth (m)	Ore Zone*	Horizontal Stress σH** ⊥O/B	Horizontal Stress σH** ‖O/B	Vertical Stress σV	Stress Ratio ⊥σH / σV	Stress Ratio ‖σH / σV	Calculated Overburden Stress X
13 Level	580	G-Zone	30.0	15.0	9.0	3.3	1.6	15.0-19.0
14 Level	625	S-Zone	23.0	13.0	12.0	1.9	1.1	16.0-20.0
		S-Zone	31.0	20.0	16.0	1.9	1.3	16.0-20.0
		L-Zone	25.0	17.0	20.0	1.3	0.9	16.0-20.0
15 Level	670	A-Zone	50.0	29.0	22.0	2.3	1.3	17.0-22.0
22 Level	990	L-Zone	53.0	23.0	19.0	2.8	1.2	26.0-32.0
27 Level	1220	L-Zone	70.0	44.0	41.0	1.7	1.1	32.0-40.0

*) The ore zones next to the stress determination sites; a mean trend of N20°W for G-Zone, and N120°E for the remaining ore zones are used as inputs for the stress calculations.

**) Horizontal stress perpendicular (⊥O/B) and parallel (‖O/B) to the orebody.

X) Calculated overburden stress from vertical stress gradients of 0.0260 to 0.0324 MPa/m (from the range for density of the overburden rock 2650 kg/m^3 to 3300 kg/m^3).

Average stress gradients (Figure 7): Vertical stress, σV = 0.0265 MPa/m
σH perpendicular O/B = 0.055 MPa/m
σH parallel O/B = 0.030 MPa/m

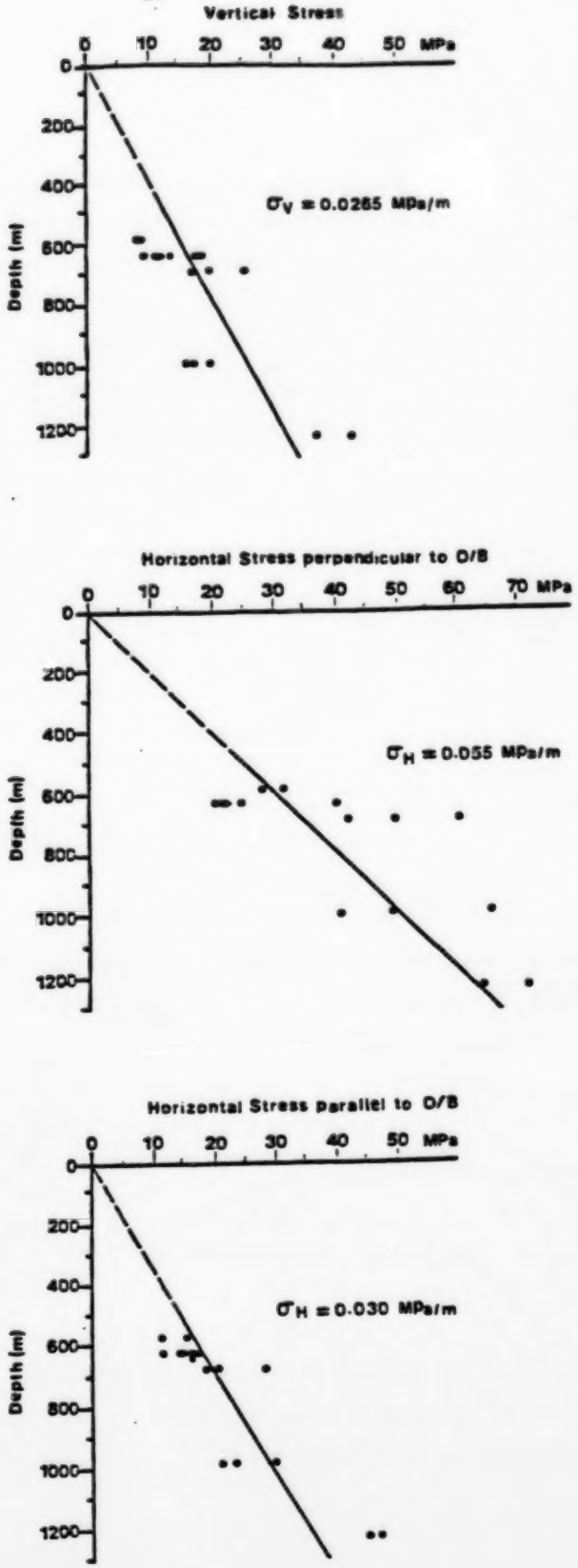

Fig. 7 - Pre-mining stress components at depth between 580 to 1220 m, CRL Mine.

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Appendix A

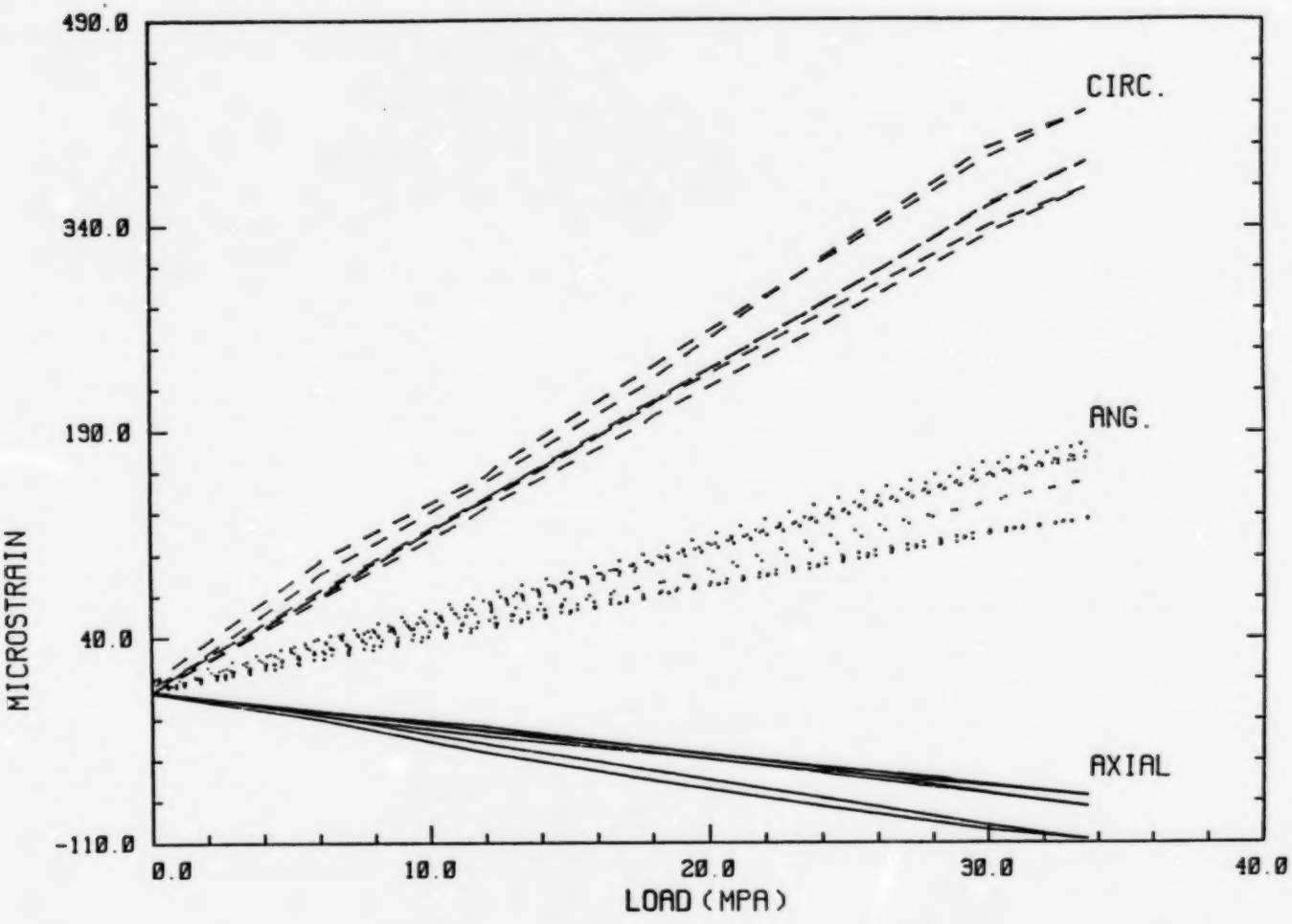

Fig. A-1 - Gauge response and linearity from loading cycle in uniaxial compression.

Table A-1 - Normal distribution of strain deviations from group means.

Gauge No:	1	2	3	4	5	6	7	8	9	10	11	12
						Strain ($\times 10^{-6}$)						
Test No. CRL 14-11	120	235	190	185	120	340	345	130	140	100	60	110
CRL 14-12	295	270	130	145	495	235	105	370	80	100	90	80
CRL 14-13	135	185	120	80	350	100	145	420	390	280	160	200
Group Mean:	185	230	146	136	321	225	198	306	203	160	103	130

Deviation from group means:	-201	-177	-125	-123	-93	-63	-63	-60	-60	-56	-53	-50
Probability	1.4	4.2	6.9	9.7	12.5	15.3	18.0	20.8	23.6	26.4	29.2	31.9
	-48	-45	-43	-26	-20	-16	-13	5	8	10	28	40
	34.7	37.5	40.3	43.0	45.8	48.6	51.4	54.2	56.9	59.7	62.5	65.3
	43	48	56	63	70	111	113	115	120	146	173	187
	68.0	70.8	73.6	76.4	79.2	81.9	84.7	87.5	87.5	90.3	95.8	98.6

Note: Deviations from the group means in order of ascending values, plotted on x-axis; probability value for individual deviation defined by [100(2r - 1)/2n], plotted on the probability scale (y-axis), r = number of deviations (1 to 36), n = total number of deviations (36), e.g., the first strain deviation (r = 1) which is -201 is plotted on the probability axis as: 100(2 x 1 - 1)/2 x 36 = 1.4%.

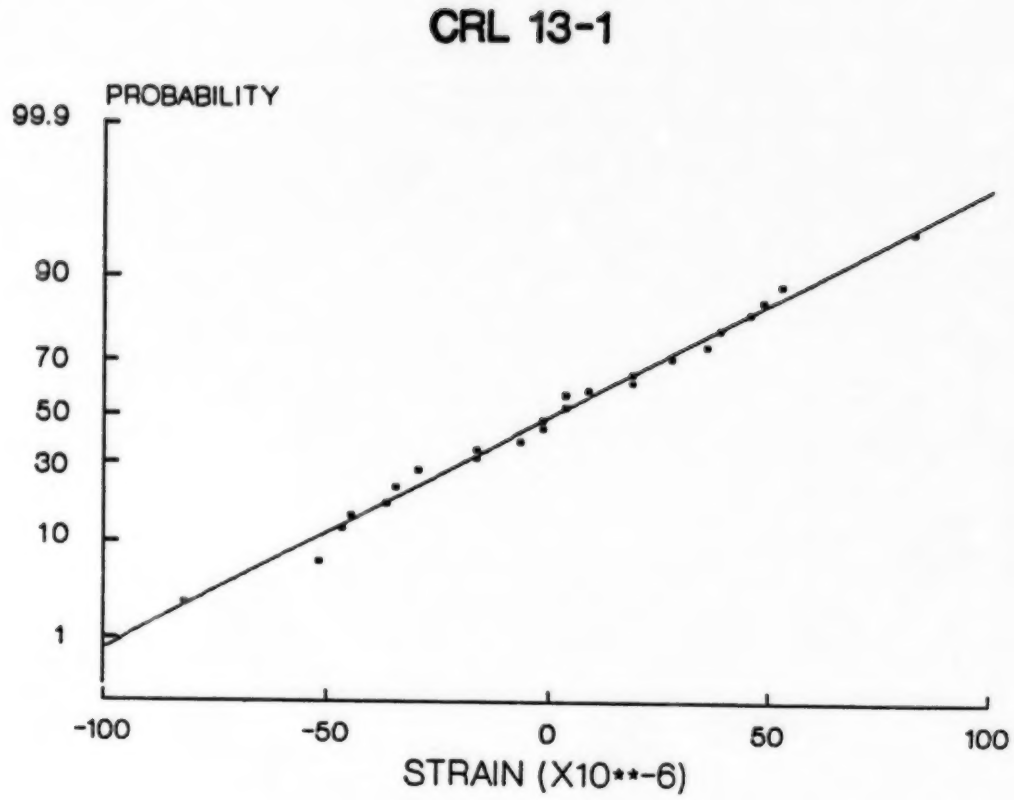

Fig. A-2 - Cumulative distribution of observed deviations from group means, stress determination site CRL 13-1.

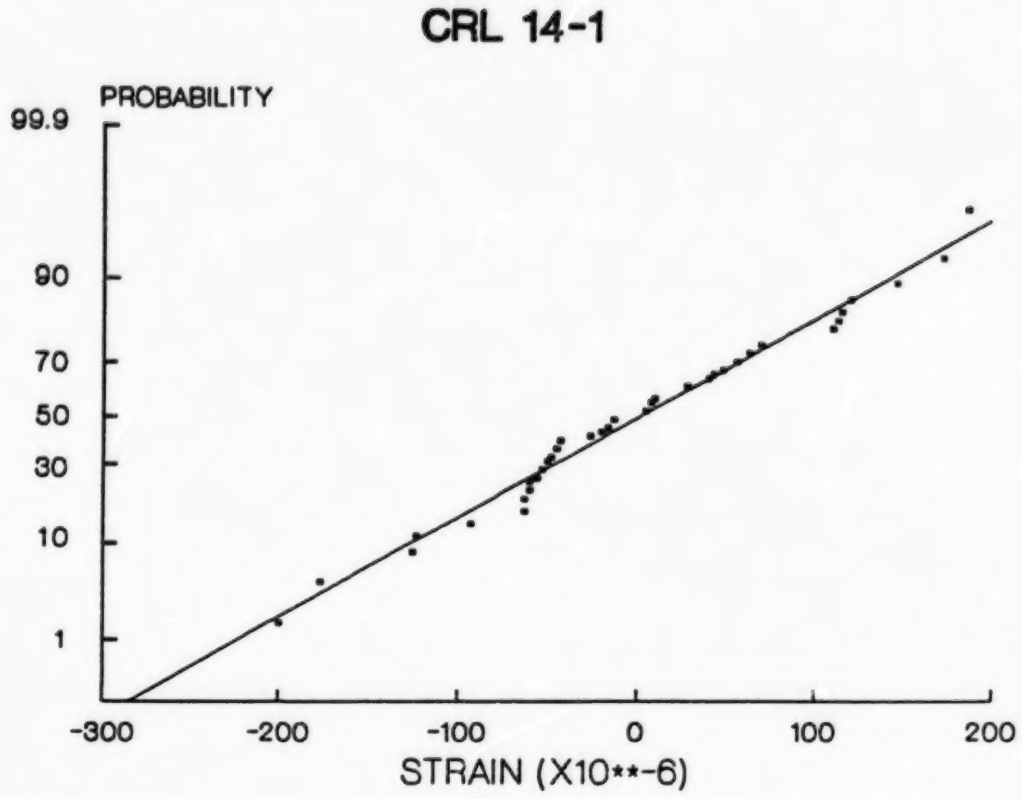

Fig. A-3 - Cumulative distribution of observed deviations from group means, stress determination site CRL 14-1.

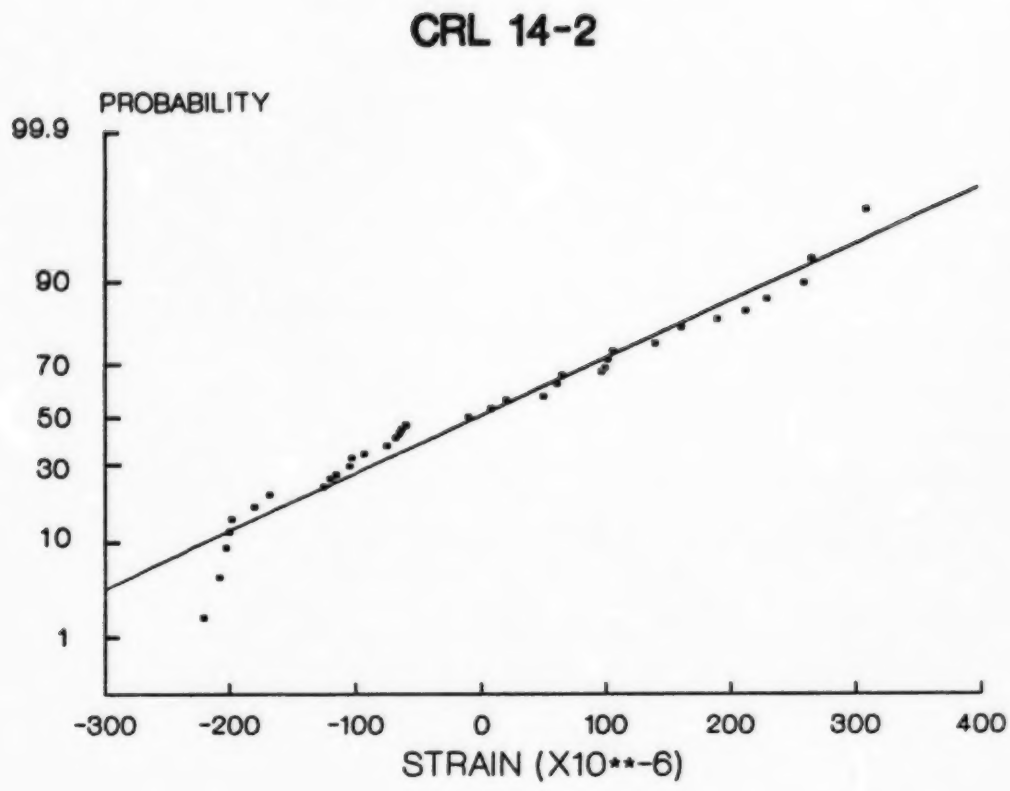

Fig. A-4 - Cumulative distribution of observed deviations from group means, stress determination site CRL 14-2.

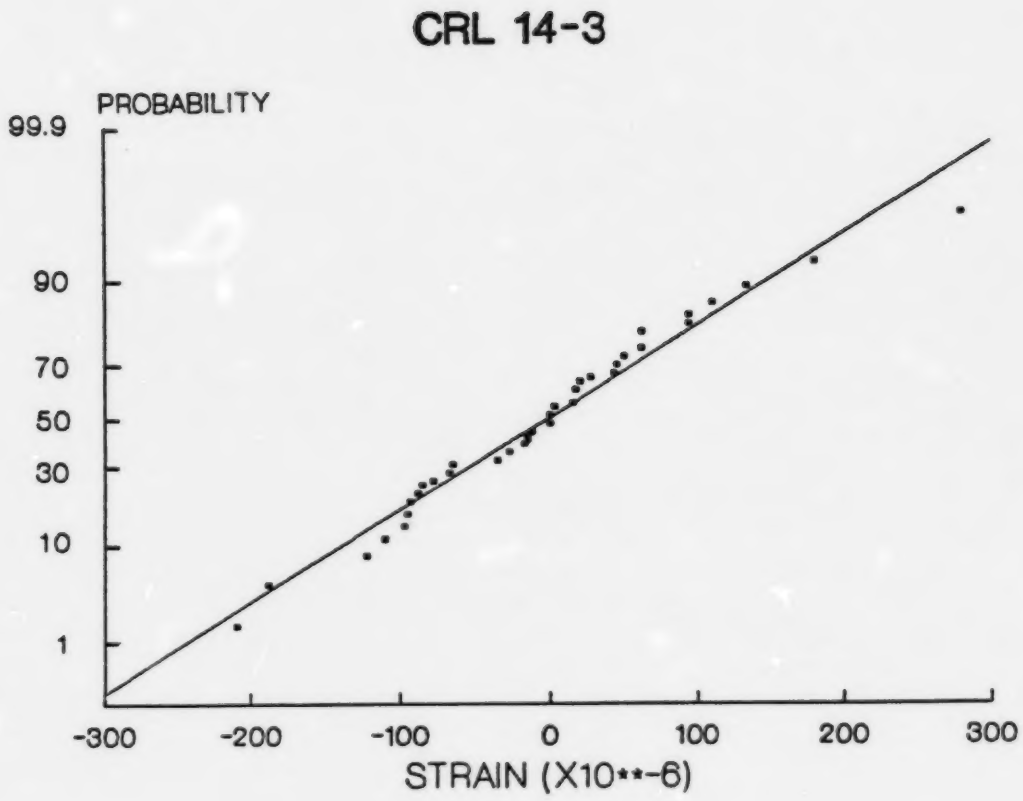

Fig. A-5 - Cumulative distribution of observed deviations from group means, stress determination site CRL 14-3.

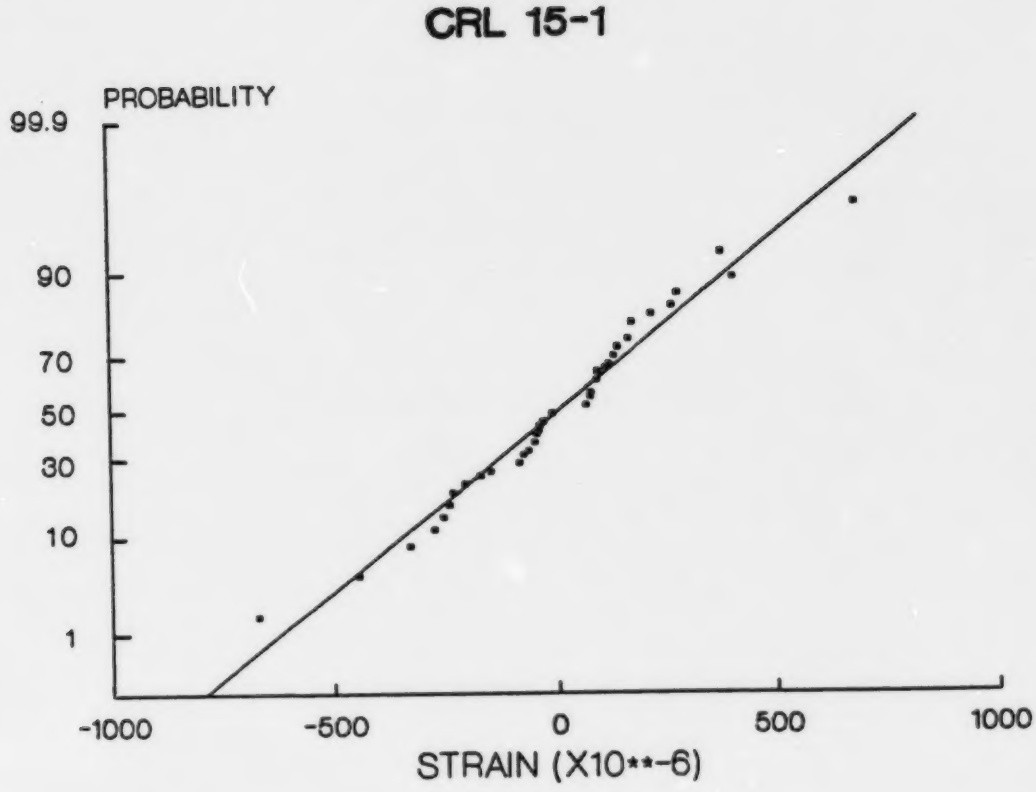

Fig. A-6 - Cumulative distribution of observed deviations from group means, stress determination site CRL 15-1.

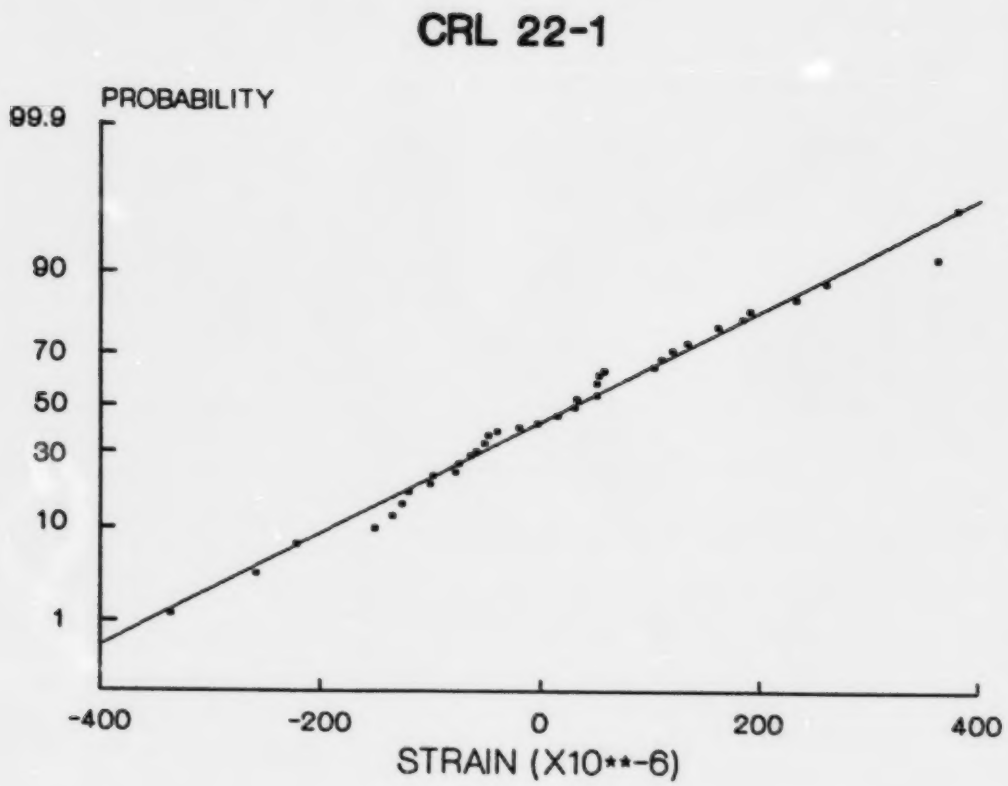

Fig. A-7 - Cumulative distribution of observed deviations from group means, stress determination site CRL 22-1.

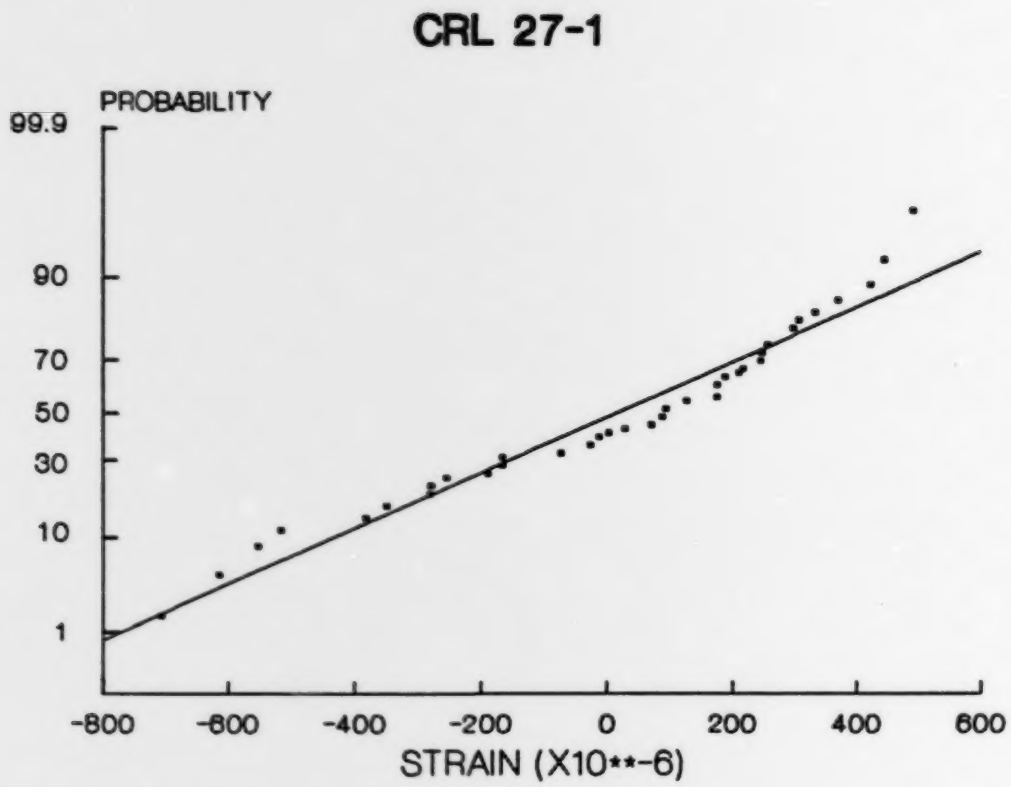

Fig. A-8 - Cumulative distribution of observed deciations from group means, stress determination site CRL 27-1.